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(54) **Acceleration sensor**

(57) An acceleration sensor for measuring an acceleration (b) in more than one coordinate directions (x, y) comprises a mass (12) which is fixed at one end and which is provided with a first electric contact element at a free end. The mass (12) is surrounded by a plurality of second electric contact elements (13 to 20) such that the first electric contact element is deflected into contact with one or two of the second electric contact elements (13-20), when a predetermined acceleration threshold value is exceeded in a given direction (b).

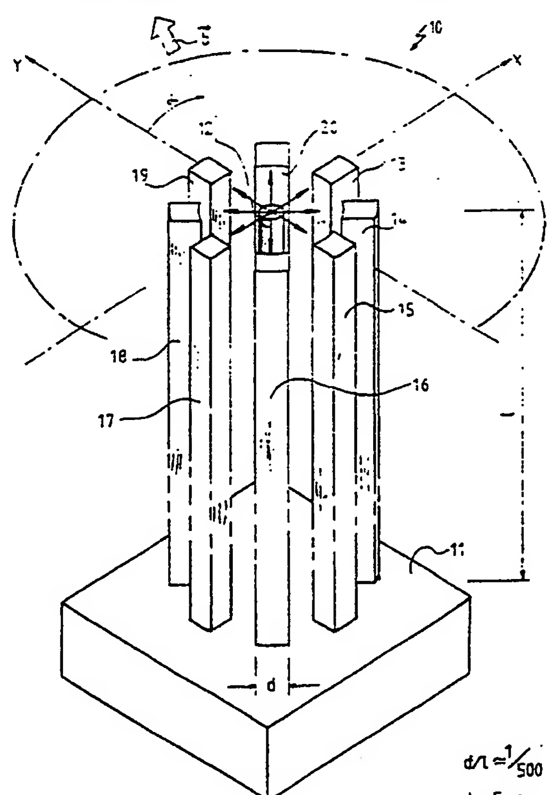


Fig 1

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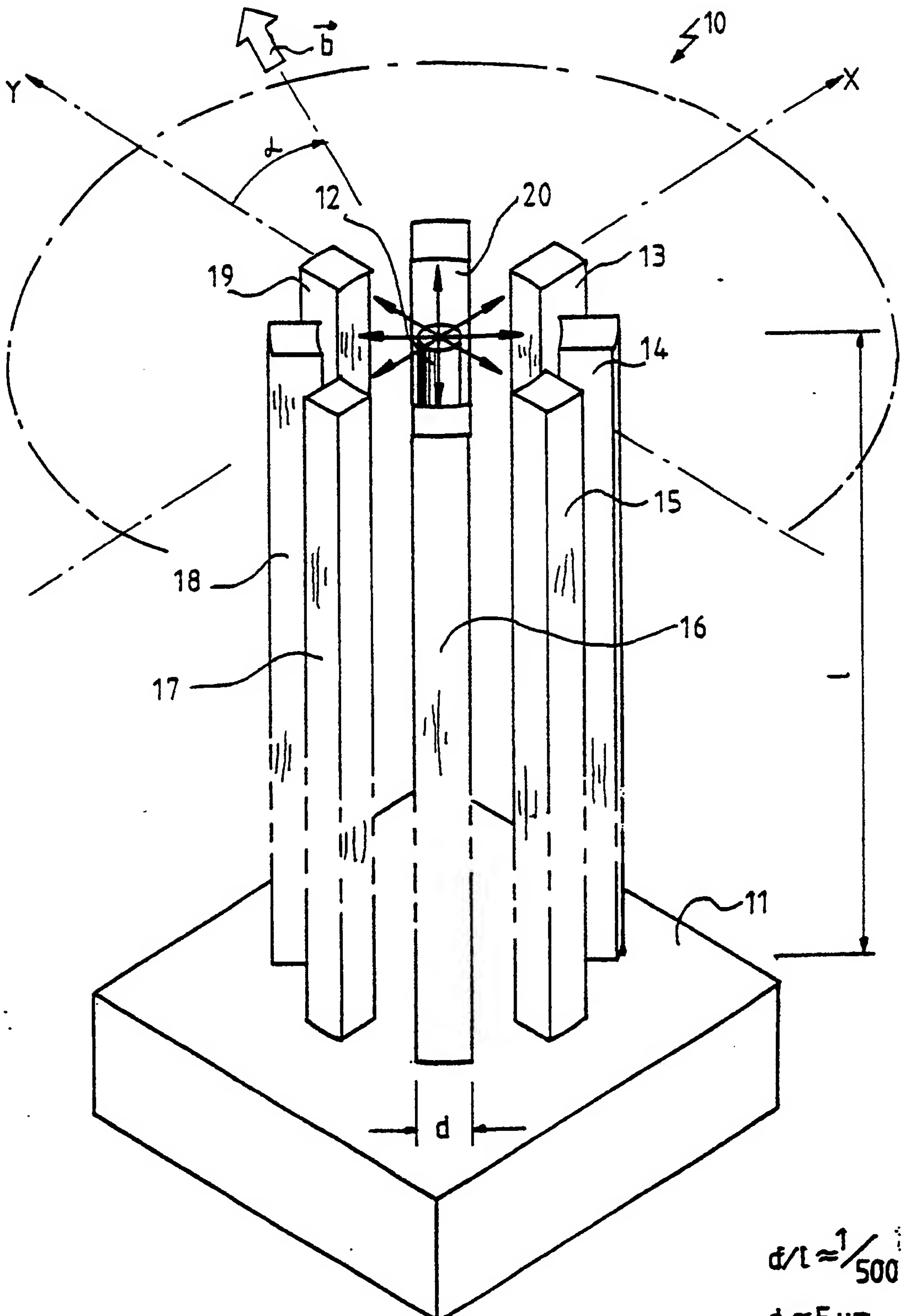


Fig 1

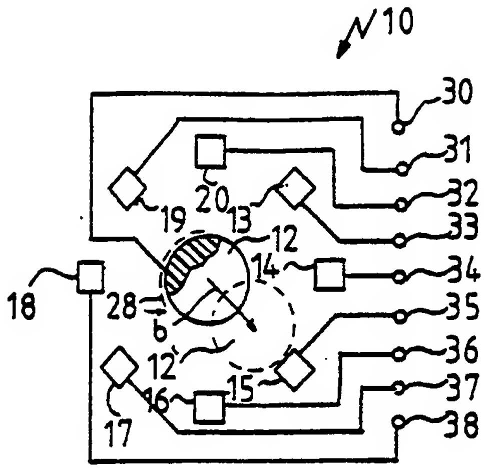


Fig 2

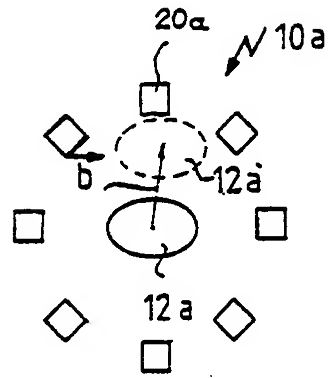


Fig 3

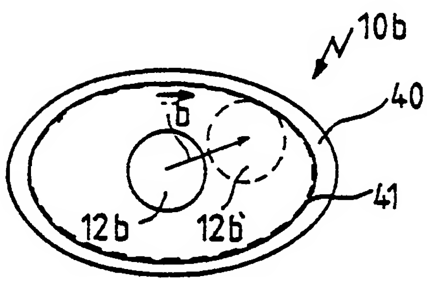


Fig 4

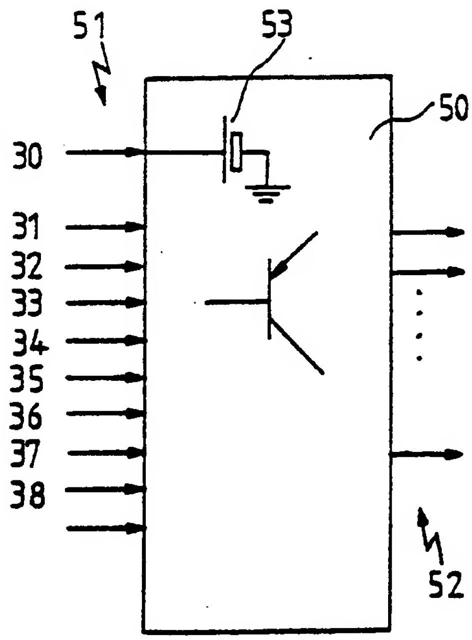


Fig 5

| α | 31 | 32 | 33 | 34 | 35 |
|---|---|---|---|---|---|
| ? | Ø | Ø | Ø | Ø | Ø |
| 0° | 1 | Ø | Ø | Ø | Ø |
| 22.5° | 1 | 1 | Ø | Ø | Ø |
| 45.0° | Ø | 1 | Ø | Ø | Ø |
| 67.5° | Ø | 1 | 1 | Ø | Ø |

Fig 6

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## Acceleration sensor and method for producing the same

The present invention relates to an acceleration sensor for measuring an acceleration in more than one coordinate directions, comprising a mass that can be deflected in one plane, the mass being provided with a first electric contact element and surrounded in the said plane by a plurality of second electric contact elements in a manner such that the first electric contact element will get into contact with one or more of the second electric contact elements in response to the direction of the acceleration in the plane to be measured, when a predetermined acceleration threshold value is exceeded.

An acceleration sensor of the type described above has been known already from DE-OS 21 22 471.

The present invention further relates to a method for producing an acceleration sensor of the type described above.

Acceleration sensors have been known in many different designs. Most of the known acceleration sensors use a spring-and-mass system where the mass is deflected under the effect of the acceleration and the deflection is then transformed into an analog electric signal.

There have further been known acceleration sensors of the binary type, which means that they only indicate whether or not a given acceleration threshold value has been exceeded. It has been known in this connection, on the one hand, to couple sensors of the analog type with an electronic circuit arrangement, in particular a comparator, in order to detect whether or not a given threshold value has been exceeded; on the other hand, however, there have also been known acceleration sensors where the mechanical measuring system as such is designed in such a manner that a given logic signal will be produced only when a predetermined acceleration threshold value is exceeded.

The before-mentioned DE-OS 21 22 471 describes a sensor arrangement comprising a metallic ball arranged on a conductive support in the form of a circular disk. The support is provided with a central bore having a diameter smaller than the diameter of the ball. A magnet is arranged underneath the bore. In the rest condition, the ball is seated in the opening of the bore and is in addition fixed in this rest position by the magnet. Above the ball, there is provided an axially symmetrical rim of contact elements

which are distributed along a surface exhibiting the shape of a truncated cone. In the rest position, these contact elements are arranged at a certain distance from the ball. Now, when the ball is moved out of its rest position, under the action of an acceleration, the force connecting the ball and the magnet is interrupted and the ball will roll laterally on the conductive support in the direction determined by the acceleration or the deceleration. At the end of a given travel, the upside of the ball will get into contact with one of the contact elements and, consisting itself of a conductive material, the ball then closes the electric circuit between the contact element and the conductive support so that the direction of travel of the ball and, accordingly, the direction of the acceleration can be determined as a function of the particular contact element that has been contacted by the ball.

However, it is a disadvantage of the known sensor arrangement that the ball is not guided on its way between its rest position, where it is retained by the magnet, and its contact position so that errors cannot be excluded when the ball is subjected to additional forces during its travel, which then have a substantially higher influence on the path of the ball because the movements of the ball are no longer restricted during its travel by any restraining forces. In addition, the rest position of the ball is relatively instable, and the known sensor arrangement permits only one installed position, i.e. the one in which the conductive support extends in a horizontal plane.

A sensor known from EP-OS 251 048 uses a pendulum consisting of a fiber-optical waveguide and a mass. In this case, the point where the light beam emitted by the fiber-optical waveguide impinges

upon a plane is monitored to detect if the point of impingement lies within a predetermined circular surface (isotropic measurement) or within an elliptical surface (anisotropic measurement).

There have further been known acceleration sensors using mechanical spring-and-mass systems where the mass is mechanically coupled to its environment over the whole travel of the movable sensor element so that the mass is mechanically guided along its way between its rest position and its deflected position. However, in the case of the known sensors of this type the direction of deflection of the sensor element is predetermined by its very design.

It has also been proposed, for measuring an acceleration in more than one coordinate directions, to use two or three sensors where the mass of each spring-and-mass system can be deflected along one coordinate direction. In the case of these known acceleration vector sensors, the electric analog signals produced in this manner are added vectorially with the aid of electronic circuit means so that they can be indicated and evaluated by amount and direction.

Acceleration sensors for one or more-dimensional measurements are in use for the most different applications. Binary acceleration sensors are used substantially for recognizing extreme situations, as for example in the case of passenger safety systems where they serve for releasing an airbag or for actuating a belt pre-load device. On the other hand it has been known to use such binary acceleration sensors for monitoring machines and systems, for example in order to detect inadmissible self-resonance situations in such machines or installations.

In certain applications of the type described above it must be monitored if a given acceleration threshold value has been exceeded in a given direction of acceleration, or in which direction an acceleration exceeding a given threshold value has occurred. It is a general requirement in all such cases that the acceleration sensor be realized with the least possible and the simplest possible components and the smallest possible dimensions, in order to permit reliable and trouble-free measurements even under very confined space conditions.

There has further become known from DE-OS 35 20 383 a crash indicator intended for application in monitoring front-end collisions of motor vehicles. The known indicator also uses a ball-shaped contact element arranged at the center of a spherical, outwardly rising calotte. When subjected to an acceleration or deceleration, the ball will roll outwardly and upwardly in the direction of action of the acceleration or deceleration. The calotte is equipped with a plurality of contact paths which are provided in annular arrangement and subdivided into sectors so as to enable the path of movement of the ball to be measured by amount and direction.

However, this known crash indicator is also connected with the same disadvantages that have been described above, in connection with the sensor arrangement known from DE-OS 21 22 471.

Finally, there have been known methods for producing acceleration sensors where the measuring system as such is constituted by chemical processes, rather than being composed of discrete mechanical elements.

For example, it has been known from US-Z-IEEE "TRANSACTIONS ON ELECTRON DEVICES", VOL. ED-26, NO. 12, DECEMBER 1979,

pages 1911 to 1917, to produce an acceleration sensor from a silicon substrate board by the application of etching processes.

However, this known method is suited only for the production of silicon-based acceleration sensors. Being a ceramic material, silicon has, however, a very high rigidity so that the response behavior must be planned appropriately. In addition, there is a risk, due to the rigidity of the ceramic material, that the sensor element may start oscillating.

Now, it is the object of the present invention to provide an acceleration sensor of the type described above, and a method for producing the same, which permit the implementation of acceleration sensors offering the greatest possible degree of operating safety, combined with very small dimensions, which can be operated in any desired installed position, and which, finally, are simple to produce.

In the case of the acceleration sensor described above, this object is achieved according to the invention by the fact that the mass is part of a mechanical spring-and-mass system which is designed as a unilaterally fixed bending rod whose free end carries the first electric contact element.

This solves the object underlying the present invention fully and perfectly because the use of a mechanical spring-and-mass system guarantees reliable guiding of the movable sensor element over its entire range of movement due to the fact that the movable mass is guided at all times. In the case of the bending rod used according to the invention this is achieved due to the fact that the deflected free end of the bending rod remains at all times connected mechanically

with the plate in which the bending bar is fixed. In addition, the acceleration sensor according to the invention can be used in any desired installed position because the bending rod arrangement can operate in any position, i.e. in a vertical, horizontal or in any other position, relative to the center of the earth.

Although it is normally preferred to arrange the second electric contact elements on a circular path surrounding the first electric contact element, it is also possible, according to a preferred embodiment of the invention, to arrange the second electric contact elements on an elliptical path around the first electric contact element.

This feature provides the advantage that it is possible in this manner to have the acceleration threshold values weighed in response to the sense of acceleration in the plane, in a manner that can be freely predetermined by the sensor itself, due to the fact that different paths have to be travelled in the different directions before the electric contact elements come into contact with each other.

It is understood in this connection that the elliptical shape of the path is described by way of example only and that instead of the elliptical path any other non-circular path may be used as well.

According to a particularly preferred embodiment of an acceleration sensor according to the invention, the spring-and-mass system is designed as a unilaterally fixed bending rod whose free end carries the first electric contact element. This feature provides the advantage that an extremely simple design is obtained where the only movable element consists of the bending rod whose flexural rigidity can be

predetermined within broad limits, in particular in micro-dimensions, by suitable selection of its dimensions, shape and material, depending on the requirements of the particular application.

According to a further improvement of the embodiment described last, the bending rod is made from a material having a high internal friction, in particular a plastic material, and is provided with an all-round metallization, at least on its free end.

This feature provides the advantage that self-resonances of the bending rod are largely suppressed due to the high internal friction of the material used. The all-round metallization provides the advantage that the bending rod can be equipped with contact-making properties on all sides by technologically simple production steps, in spite of the use of an electrically non-conductive material.

In certain other embodiments of the invention, the bending rod is designed as a circular cylinder.

The advantage of this design lies in the fact that an isotropic response behavior is obtained because the unilaterally fixed circular cylindrical bending rod has the same rigidity in all bending directions.

According to an alternative of this design, the bending rod has the shape of a cylinder of elliptical cross-section.

This feature, too, offers the possibility to achieve a predetermined anisotropy of the response behavior. It is again understood in this connection that the elliptical cross-section is described only as an example representative of many other possible non-circular cylindrical shapes.

According to a particularly preferred embodiment of the invention, the second electric contact elements are designed as rigid bars arranged on a common substrate board with the bending rod.

This feature provides the advantage that one obtains again an extremely simple, in the extreme case even a monolithic, design which is particularly simple to produce and extremely insensitive to trouble, due to its simple structure.

According to another embodiment of the acceleration sensor described before, the bars consist of a metallic material.

This feature provides the advantage that any contact made between the bending rod and the bars can be detected by tapping the voltage at the bar in any desired manner, without any need for the arrangement of additional contact elements, lines, or the like, on the bars.

According to still other embodiments of the invention, the second electric contact elements are designed as conductor paths arranged on the inside of a tube surrounding the bending rod.

This feature provides the advantage that the second electric contact elements are arranged on a particularly rigid structure which is particularly resistant to the acceleration forces to which it is subjected. Arranging conductor paths on the inside of a tube provides the advantage that extremely a fine graduation can be achieved by making the conductor paths very narrow so that a very high resolution of the angle can be achieved when measuring the acceleration vector.

According to still other embodiments of the invention, an electric evaluation unit is provided for deriving from the contact between the first electric contact element and a second electric contact element an electric signal proportional of the angle of deflection of the spring-and-mass system.

This feature provides the advantage that a digital signal can be provided directly by corresponding re-coding, for being processed subsequently in usual data processing systems, for example on board of a motor vehicle.

According to a further improvement of this variant, the electric evaluation system provides a signal representative of an intermediate value when contact is made with two or more neighboring electric contact elements.

This feature provides the advantage that the resolution of the accuracy of the angle can be improved by simple means.

In the frame of the present invention, acceleration sensors in the sub-miniature range are particularly preferred where the length of the bending rod is equal to 200 to 1,000 times, in particular 500 times, its thickness and its thickness is between 1 and 10 µm, preferably 5 µm.

In the case of acceleration sensors of the type just described, the object underlying the invention is also solved by a production method according to which the bending rod, the rigid bars or the tube, as well as the substrate board, are produced by means of a lithographic-galvanotechnical imaging process (LIGA).

The details of the LIGA process have been described, for example, by the KfK report No. 3995 "Herstellen von

Mikrostrukturen... (Production of micro-structures)" published by Kernforschungszentrum Karlsruhe (Karlsruhe Nuclear Research Center) in November 1985.

This feature provides the advantage that the structure described before can be produced with high precision, but at the same time also practically without any restrictions regarding their shape, in micro-dimensions and from a plurality of possible materials, in particular from metal, plastic or ceramic materials. The possibility to produce the most different shapes enables in this case certain characteristics to be predetermined so that the response behavior of the acceleration sensor produced in this manner can be varied almost without any restrictions, depending on the requirements of the particular application.

Other advantages of the invention will appear from the specification and the attached drawing.

It is understood that the features that have been described before and will be explained hereafter may be used not only in the described combinations, but also in any other combination, or individually, without leaving the scope and intent of the present invention.

Certain embodiments of the invention will now be described in more detail with reference to the drawing in which:

Fig. 1 shows a perspective view of one embodiment of an acceleration sensor according to the invention;

fig. 2 shows a top view of the acceleration sensor illustrated in fig. 1, with the required wiring added;

fig. 3 shows a representation similar to that of fig. 2, but for another embodiment of an acceleration sensor;

fig. 4 shows another representation similar to that of fig. 2, but for still another embodiment of an acceleration sensor;

fig. 5 shows a very diagrammatic block diagram of an evaluation unit employed according to the invention; and

fig. 6 shows a truth table for the evaluation of the measuring signals of the acceleration sensor according to fig. 2.

In fig. 1, an acceleration sensor of the type used for vectorial measurements of an acceleration b in a plane defined by cartesian coordinates x and y is indicated generally by reference numeral 10.

The acceleration sensor 10 comprises a common substrate board 11 in which a bending rod 12 of circular cylindrical shape is fixed unilaterally. Around the bending rod 12 there are provided, along a circular path, contact bars 13 to 20, for example eight such bars which are distributed about the circumference of 360°, having approximately the same length as the bending rod 12. It is, however, understood that a smaller or greater number of contact bars may be arranged about the bending rod 12, depending on the particular application and the desired resolution.

Arrows 21 indicate that when the bending rod 12 is subjected to an acceleration b, it is deflected in the same sense in which the acceleration vector is directed. The amount of

deflection of the free end of the bending rod 12 is proportional to the amount of acceleration b. When the amount of acceleration b exceeds a given value, which is determined by the dimensions and the material selected for the bending rod 12 and the contact bars 13 to 20, then the bending rod 12 is deflected far enough to bring its free end into contact with one or two of the contact bars 13 to 20. If the arrangement is such that an electric contract is closed by this contact between the bending rod 12 and one or two of the contact bars 13 to 20, then this condition can be detected selectively.

It is understood that the contact bars 13 to 20 are conveniently of rigid design, compared with the elastic bending rod 12, so that they themselves will not deform under the action of an acceleration force.

From the top view of the arrangement of fig. 1 shown in fig. 2 it can be seen that the bending rod 12 consists preferably of a plastic material which may be provided about its periphery with a metallization 28. In contrast, the contact bars 13 to 20 are preferably made of a metal, as indicated for the contact bar 13, so that it can be detected in a simple manner when electric contact is made between the metallization 28 and one or two of the metallic contact bars 13 to 20.

The metallization 28 is connected for this purpose to a first terminal 30 of the acceleration sensor 10, while the contact bars 13 to 20 are connected to terminals 31 to 38, as can be seen in detail in fig. 2.

Fig. 2 further illustrates the case where the bending rod 12 is subjected to an acceleration b acting downwardly and to

the right, the amount of the acceleration b being such as to deflect the bending rod 12 into a position 12' where it just gets into contact with the contact bar 15. It is possible in this case to detect the contact between the terminals 30 and 35.

Fig. 3 shows a variant of an acceleration sensor 10a where the bending rod 12a, instead of exhibiting a circular cylindrical shape, is designed as a cylinder of elliptical cross-section. This means in the case of the arrangement illustrated in fig. 3 that an acceleration force b acting upwardly will have to exceed only a lower threshold value until contact is made, for example with the contact bar 20a, as indicated by the deflected bending rod 12a' in fig. 3, while an acceleration force acting to the right or to the left, as viewed in fig. 3, will have to exceed a considerably higher threshold value until corresponding contact is made. This is due to the fact that - as is generally known - the deflection of a unilaterally fixed bending rod of elliptical cross-section depends on its geometrical moment of inertia which is a function of the third power of the length of the main axes of the rod, in the directions of the two main axes of the elliptical cross-section.

Another variant of an acceleration sensor exhibiting anisotropic measuring behavior is illustrated in fig. 4.

In the case of this variant, the bending rod 12b has again a circular cylindrical shape, but is arranged at the center of a tube 40 of elliptical cross-section whose inside is provided with conductor paths 41.

If in this case an acceleration b acts upon the bending rod 12b, for example in a direction upwardly and to the right -

as viewed in fig. 4 - then the closed-contact condition 12b' is achieved when a certain deflection, depending on the angle, is reached, as can be derived directly from fig. 4.

It is understood in this connection that the circular cylindrical and elliptical shapes described before are to be understood only as examples and that it is of course also possible to select other shapes for the cross-section of the bending rod 12 and for the arrangement of the surrounding electric contacts, in order to weigh acceleration values acting in one direction relative to others acting in other directions.

Fig. 5 shows very diagrammatically an evaluation unit 50 comprising inputs 51 and outputs 52. A voltage source 53, which may be connected for example to the terminal 30 of the arrangement shown in fig. 2, is connected to one of the outputs 51. The metallization 28 of the bending rod 12 carries a positive electric voltage which then appears at one or two of the other terminals 31 to 38, depending on which of the contact bars 13 to 20 has been contacted by the bending rod 12.

The outputs 52 then supply a signal every time contact has been made between the bending rod 12 and any of the contact bars 13 to 20, i.e. when one of the predetermined acceleration threshold values has been exceeded, and the outputs 52 supply a usually coded, for example BCD-coded, bit pattern which is representative of the angle $\alpha$ by which the bending rod 12 has been deflected and which conforms to the direction of action of the acceleration b.

Fig. 6 finally shows a truth table in which the conditions of the terminals 31, etc., have been plotted.

In the first line of the truth table illustrated in fig. 6, the condition has been recorded in which all terminals 31 ... supply a negative logic signal. This means that no contact has been established between the bending rod 12, which carries a positive voltage, and any of the contact bars 13 to 20. Consequently, the bending rod 12 has been deflected either not at all or in a direction than cannot be detected.

If a positive logic signal is encountered at the terminal 31 only, this means, according to the angle pattern defined in fig. 1, that an angular deflection by 0° has occurred relative to the y axis. As the angle increases, contact is made at an angle value of 22.5° with two neighboring contact bars, i.e. the bars 19 and 20, so that a positive logic signal occurs at the terminals 31 and 32. As the angle $\alpha$ further increases, this pattern develops in such a manner that a positive logic signal occurs initially at the terminal 32 only, then at terminals 32 and 33, then at terminal 34 alone, and so on. It is possible in this matter to detect angles of 45°, 67.5°, 90°, etc. This is true for cases where a number of only eight contact bars 13 to 20 are arranged around the bending rod 12. By increasing the number of contact points, as indicated in fig. 4 by the narrow conductor paths 41, one can of course achieve a corresponding improvement of the resolution of the angle measurements.

Acceleration sensors of the type described above may be produced advantageously by a lithographic-galvanotechnical imaging process (LIGA) or else by etching, according to the silicon technology. It is possible in this manner to achieve extremely small dimensions for the bending rod so that no additional seismic masses have to be arranged at the free end of the bending rod, which would on the one hand reduce

the rapidity of action and, on the other hand, increase the risk of self-resonances. When applying the LIGA process, one is largely free to select the materials to be employed at desire, and to produce the desired structure from metal, plastic or ceramic materials.

## Claims:

1) Acceleration sensor for measuring an acceleration (b) in more than one coordinate directions (x, y), comprising a mass that can be deflected in one plane (x/y), the mass being provided with a first electric contact element and surrounded in the said plane by a plurality of second electric contact elements in a manner such that the first electric contact element will get into contact with one or more of the second electric contact elements in response to the direction $\alpha$ of the acceleration (b) in the plane (x/y) to be measured, when a predetermined acceleration threshold value is exceeded, characterized in that the said mass is part of a mechanical spring-and-mass system which is designed as a unilaterally fixed bending rod (12) whose free end carries the said first electric contact element.

2) Acceleration sensor according to claim 1, characterized in that the said second electric contact elements are arranged on a non-cylindrical, in particular an elliptical path around the said first electric contact element.

3) Acceleration sensor according to claim 1 or 2, characterized in that the said bending rod (12) is made from a material having a high internal friction, in particular a plastic material, and is provided with an all-round metallization (28), at least on its free end.

4) Acceleration sensor according to one or more of claims 1 to 3, characterized in that the said bending rod (12) is designed as a circular cylinder.

5) Acceleration sensor according to one or more of claims 1 to 3, characterized in that the said bending rod (12a) has the shape of a cylinder of non-circular, in particular elliptical cross-section.

6) Acceleration sensor according to one or more of claims 1 to 5, characterized in that the said second electric contact elements are designed as rigid bars (13 to 20) arranged on a common substrate board (11) together with the said bending rod (12).

7) Acceleration sensor according to claim 6, characterized in that the said bars (13 to 20) consist of a metallic material.

8) Acceleration sensor according to one or more of claims 1 to 5, characterized in that the said second electric contact elements are designed as conductor paths (41) arranged on the inside of a tube (40) surrounding the said bending rod (12).

9) Acceleration sensor according to one or more of claims 1 to 8, characterized in that an electric evaluation unit (50) is provided for deriving from the contact between the said first electric contact element and a second electric contact element an electric signal proportional to the angle ($\alpha$) of deflection of the spring-and-mass system.

10) Acceleration sensor according to claim 9, characterized in that the said electric evaluation system (50) provides a signal representative of an intermediate value when contact is made with two or more neighboring electric contact elements.

11) Acceleration sensor according to one or more of claims 1 to 10, characterized in that the length of the said bending rod (12) is equal to 200 to 1,000 times, preferably 500 times, its thickness and its thickness is between 1 and 10 µm, preferably 5 µm.

12) Method for producing an acceleration sensor (10) according to one or more of claims 6 to 11, characterized in that the said bending rod (12), the said substrate board (11), and the said rigid bars (13 to 20) or the said tube (40) are produced with the aid of a lithographic-galvanotechnical imaging process (LIGA).

13) Any of the acceleration sensors substantially as herein described with reference to the accompanying drawings.

14) Either of the methods of producing an acceleration sensor as claimed in claim 13, substantially as herein described.

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